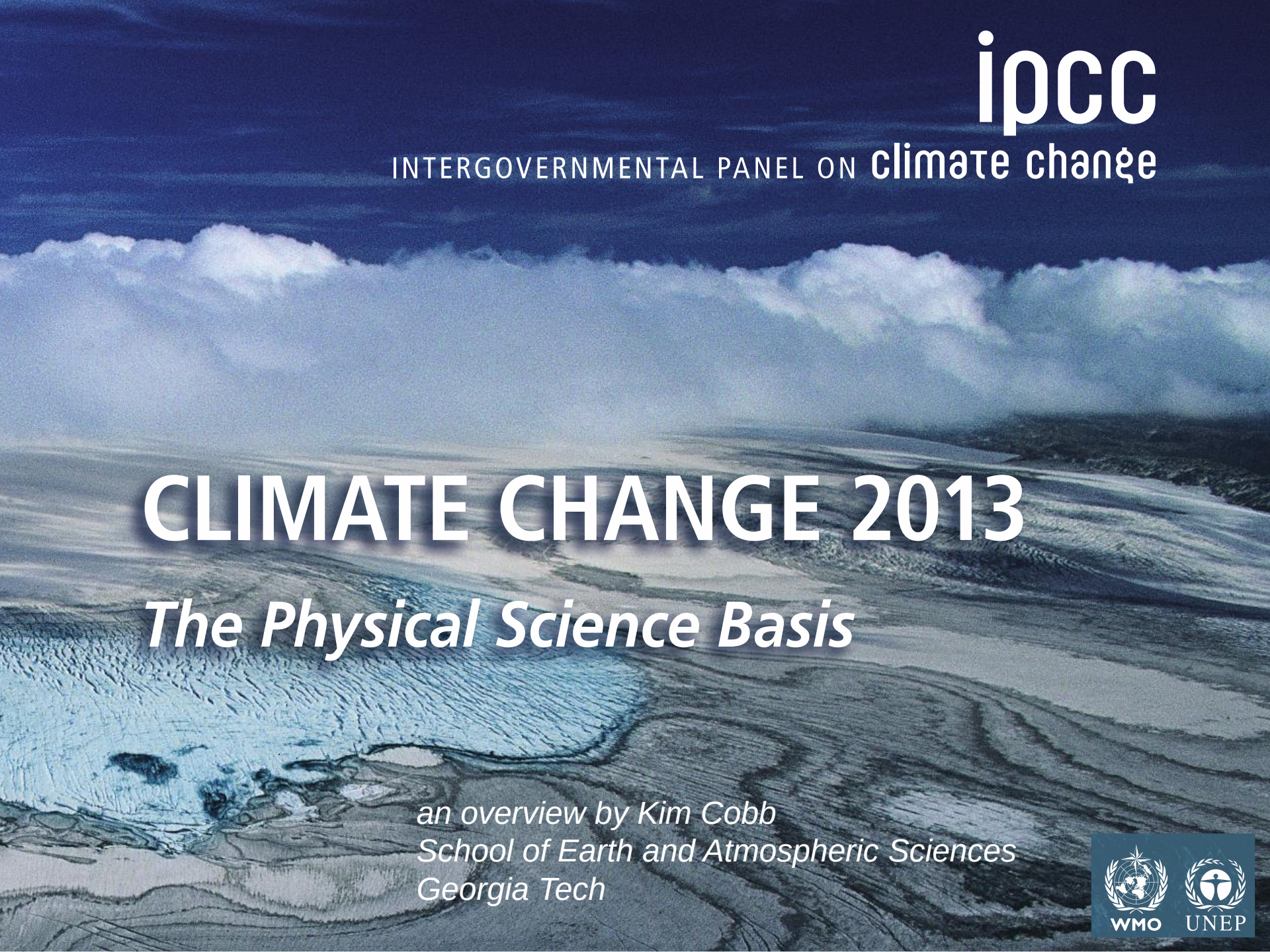
ipcc
INTERGOVERNMENTAL PANEL ON climate change
CLIMATE CHANGE 2013
The Physical Science Basis
an overview by Kim Cobb
School of Earth and Atmospheric Sciences
Georgia Tech
WMO
UNEP

AR5 Summary for Policymakers

Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes (Figure SPM.6 and Table SPM.1). This evidence for human influence has grown since AR4. It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century. {10.3–10.6, 10.9}

Human influence detected in:

warming

global water cycle

melting ice/snow

sea level rise

increase in climate extremes

AR5 Summary for Policymakers

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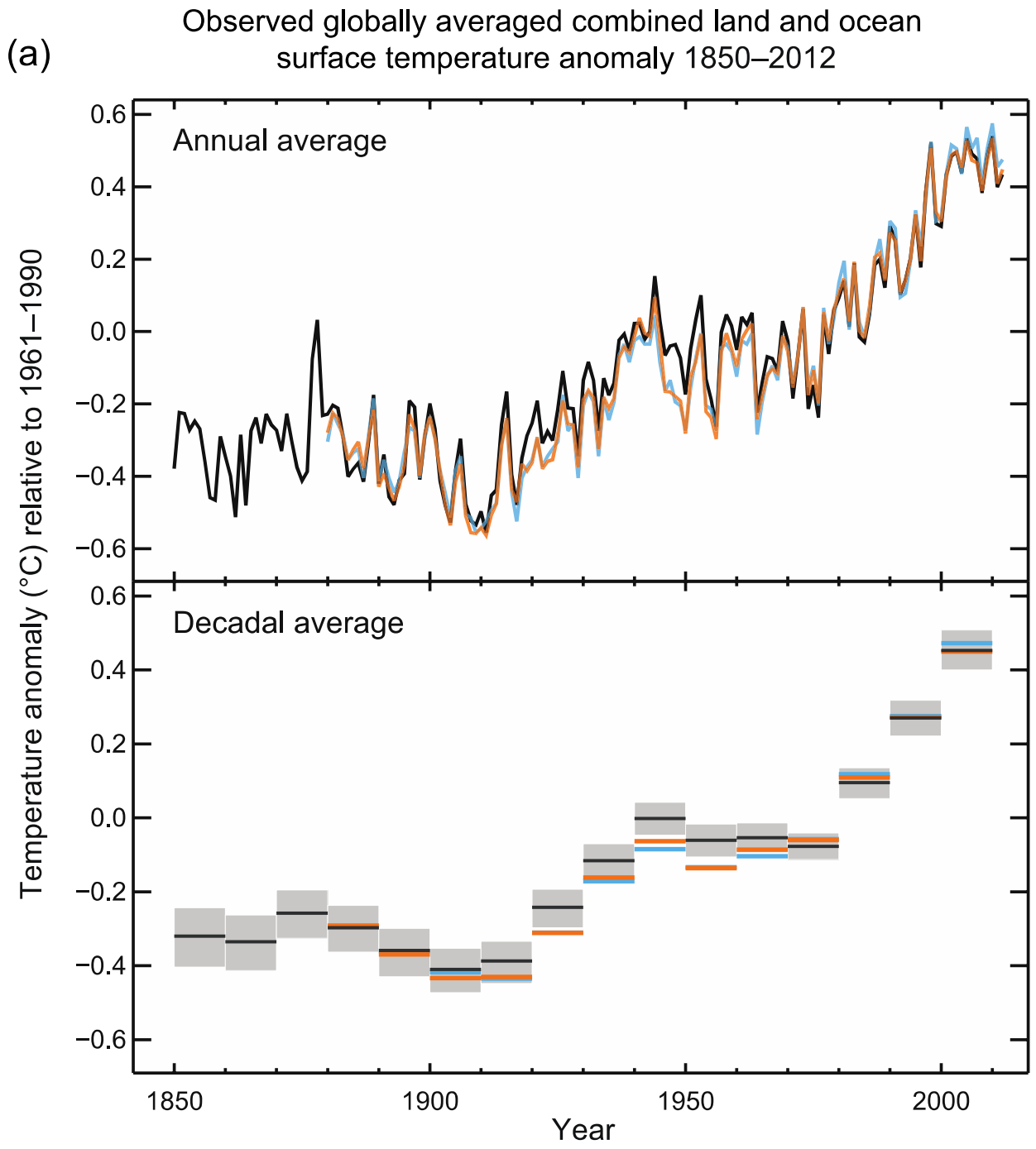


NOTE:
all graphs from IPCC AR5 unless otherwise noted

Is there a pause in global warming?

Rising(Upper(Ocean(Temperature(

nature climate change

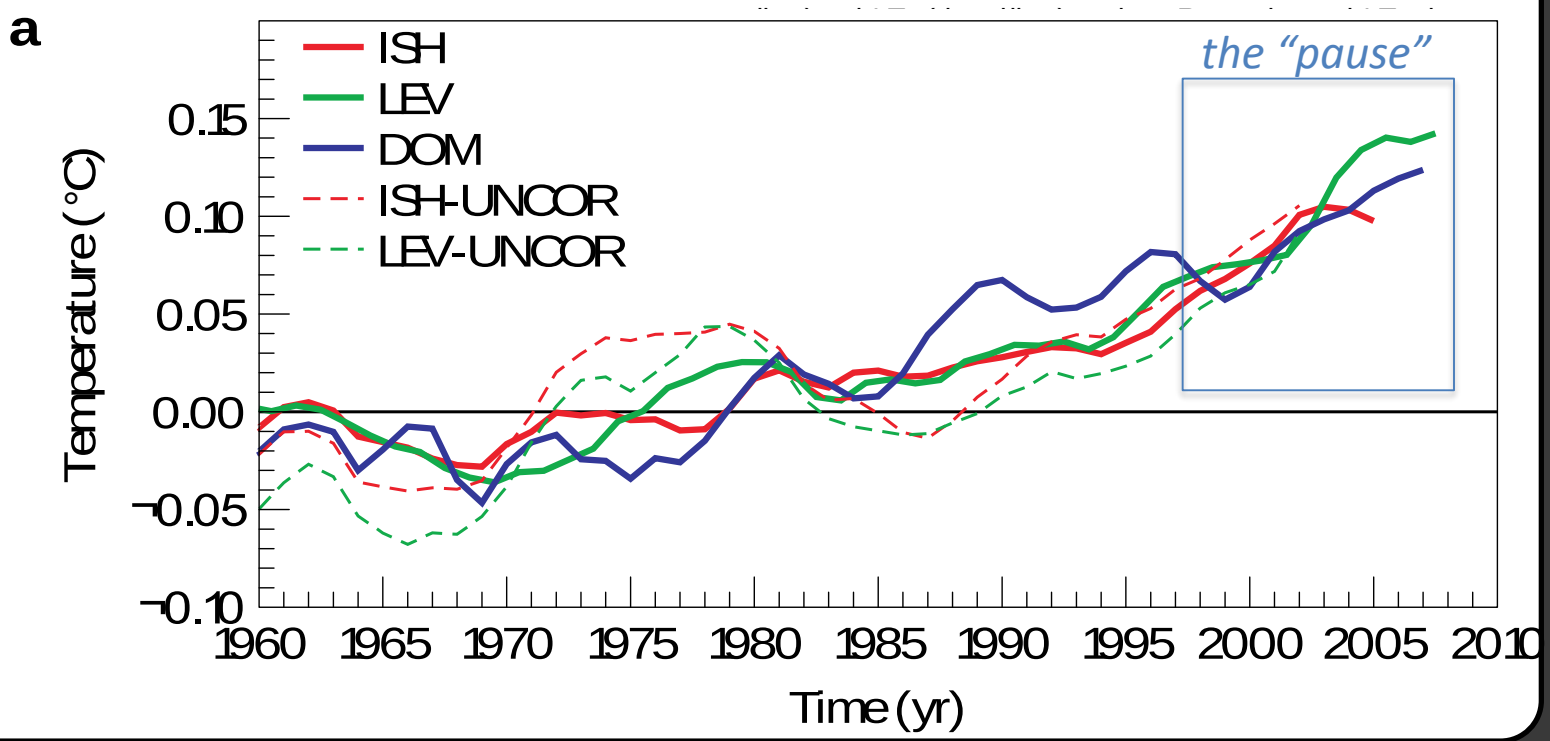
LETTERS

PUBLISHED ONLINE: 10 JUNE 2012 | DOI: 10.1038/NCLIMATE1553

Human-induced global ocean warming on multidecadal timescales

P. J. Gleckler[1]*, B. D. Santer[1], C. M. Domingues[2,3], D. W. Pierce[4], T. P. Barnett[4], K. E. Taylor[1], K. M. AchutaRao[5], T. P. Boyer[6], M. Ishii[7] and P. M. Caldwell[1]

Figure 1 | Global mean *1 T* (0–700 m) with respect to a 1957–1990 climatology. **a**, Estimates of Domingues *et al.*[7] (DOM), Ishii *et al.*[8] (ISH) and Levitus *et al.*[9] (LEV), all of which have been corrected for XBT biases. Earlier (uncorrected) estimates of Ishii *et al.*[10] (ISH-UNCOR) and Levitus *et al.*[11] (LEV-UNCOR) are also shown. **b**, ISH and LEV *1 T*$_{IF}$ (solid



Changes in global water cycle: observed

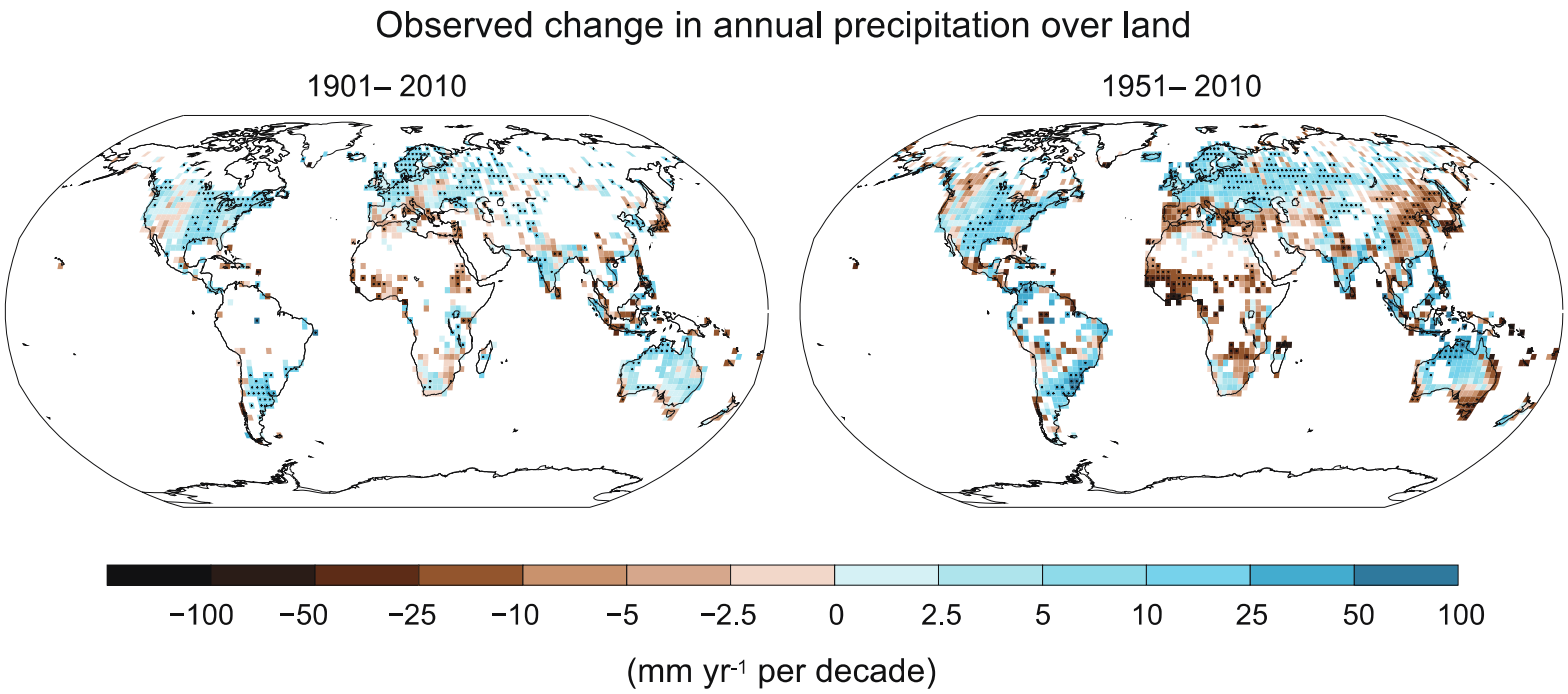
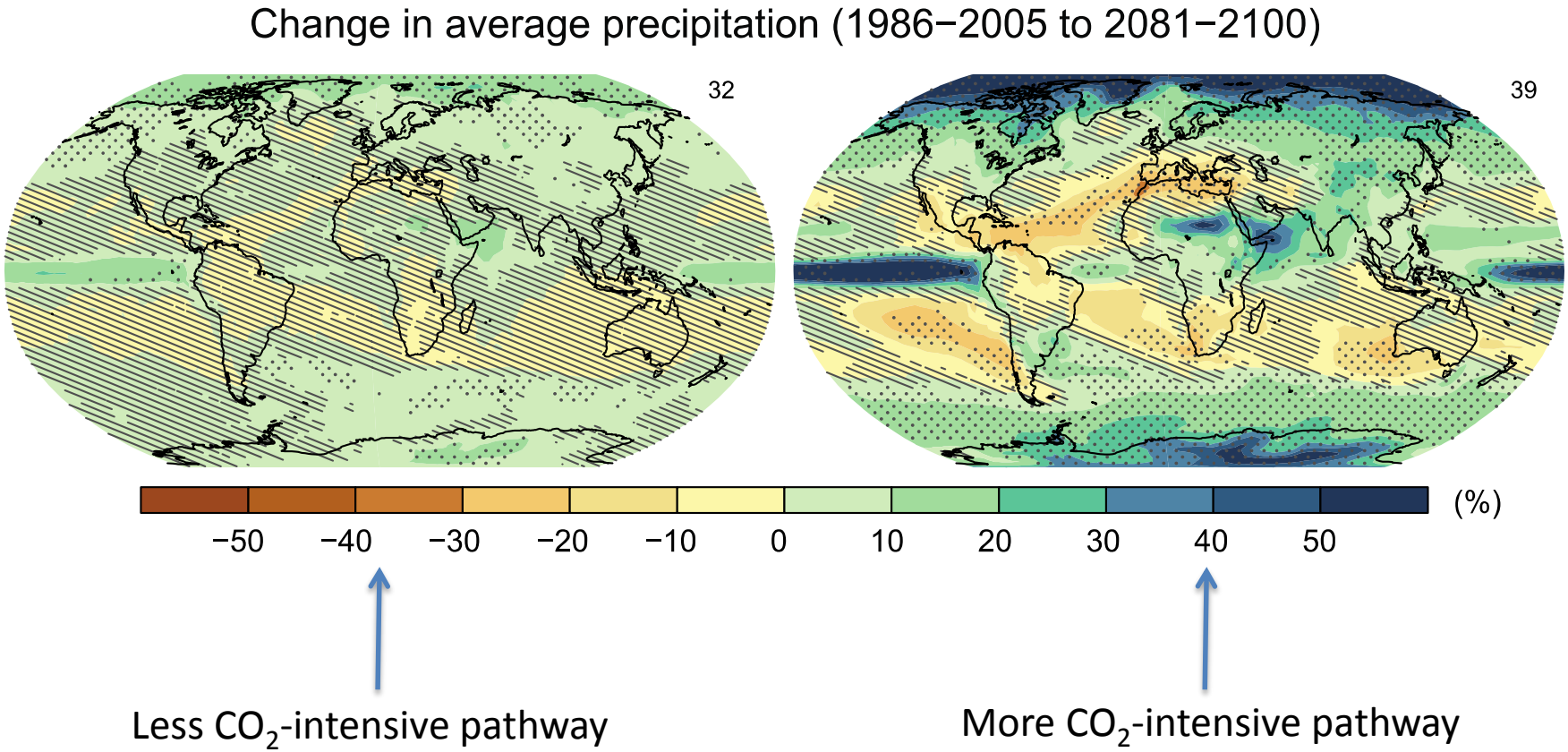


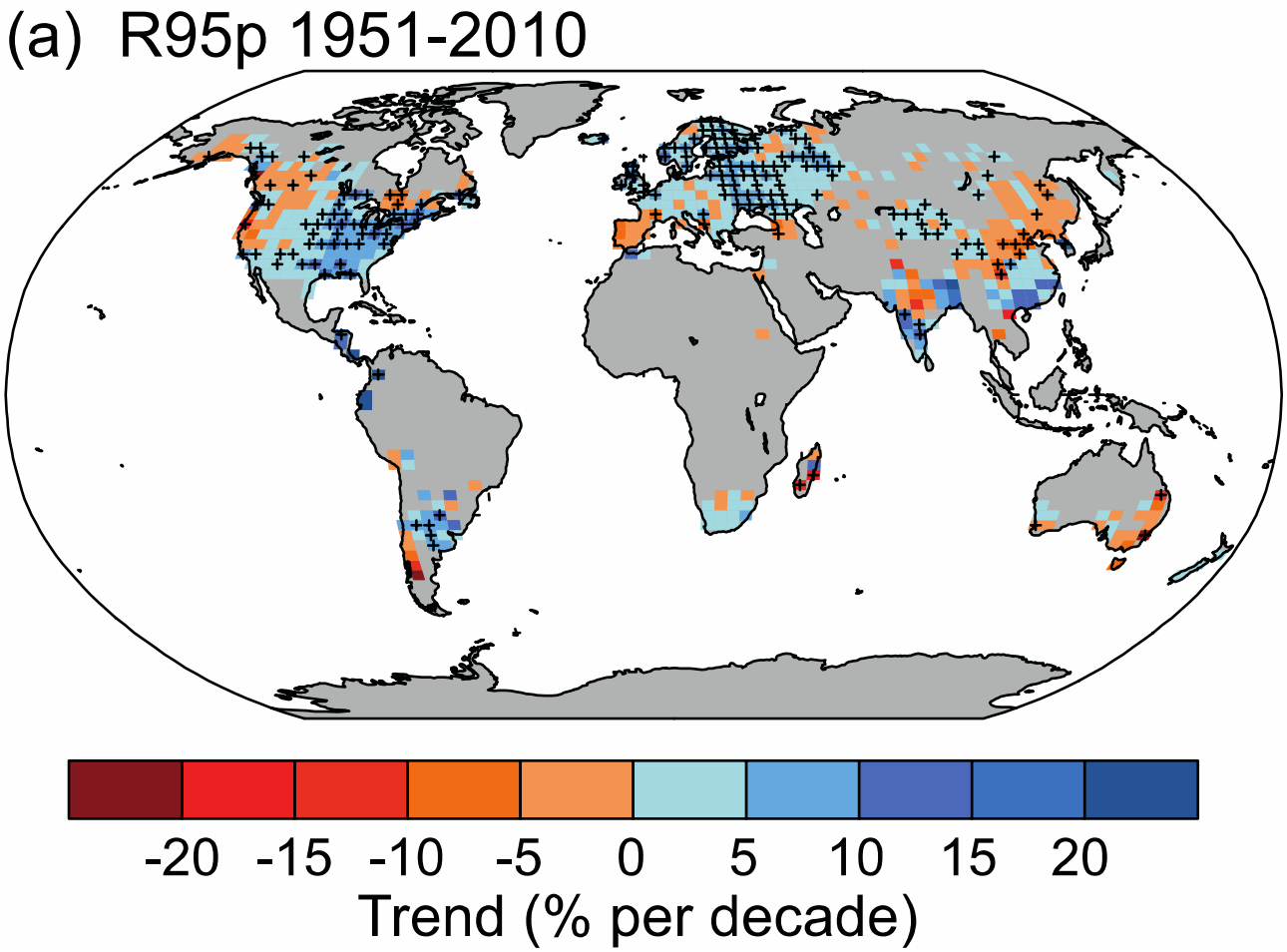
Figure SPM.2 | Maps of observed precipitation change from 1901 to 2010 and from 1951 to 2010 (trends in annual accumulation calculated using the same criteria as in Figure SPM.1) from one data set. For further technical details see the Technical Summary Supplementary Material. {TS TFE.1, Figure 2; Figure 2.29}

Changes in global water cycle: projections



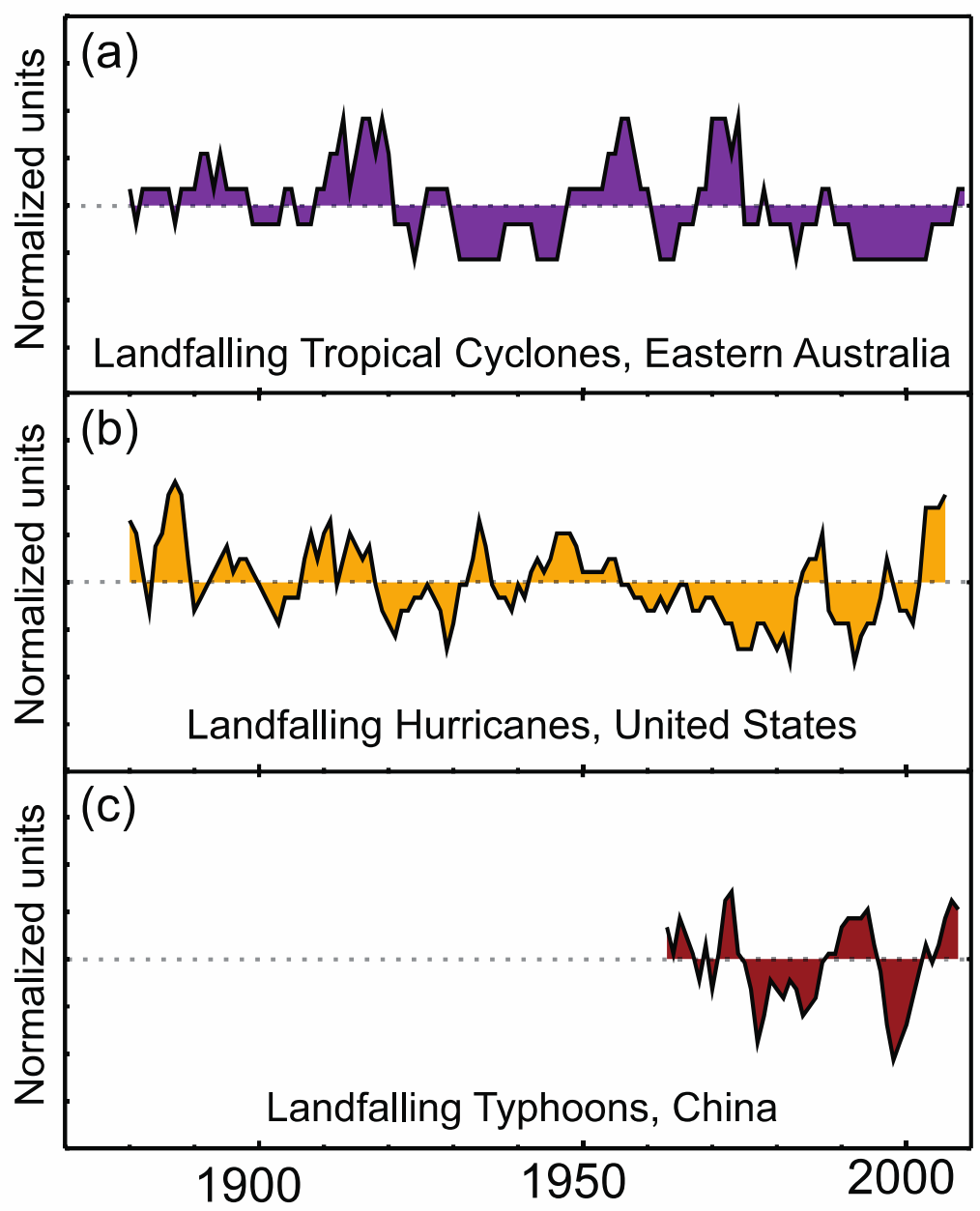
"wet get wetter, dry get drier"

Changes in extreme precipitation: observed



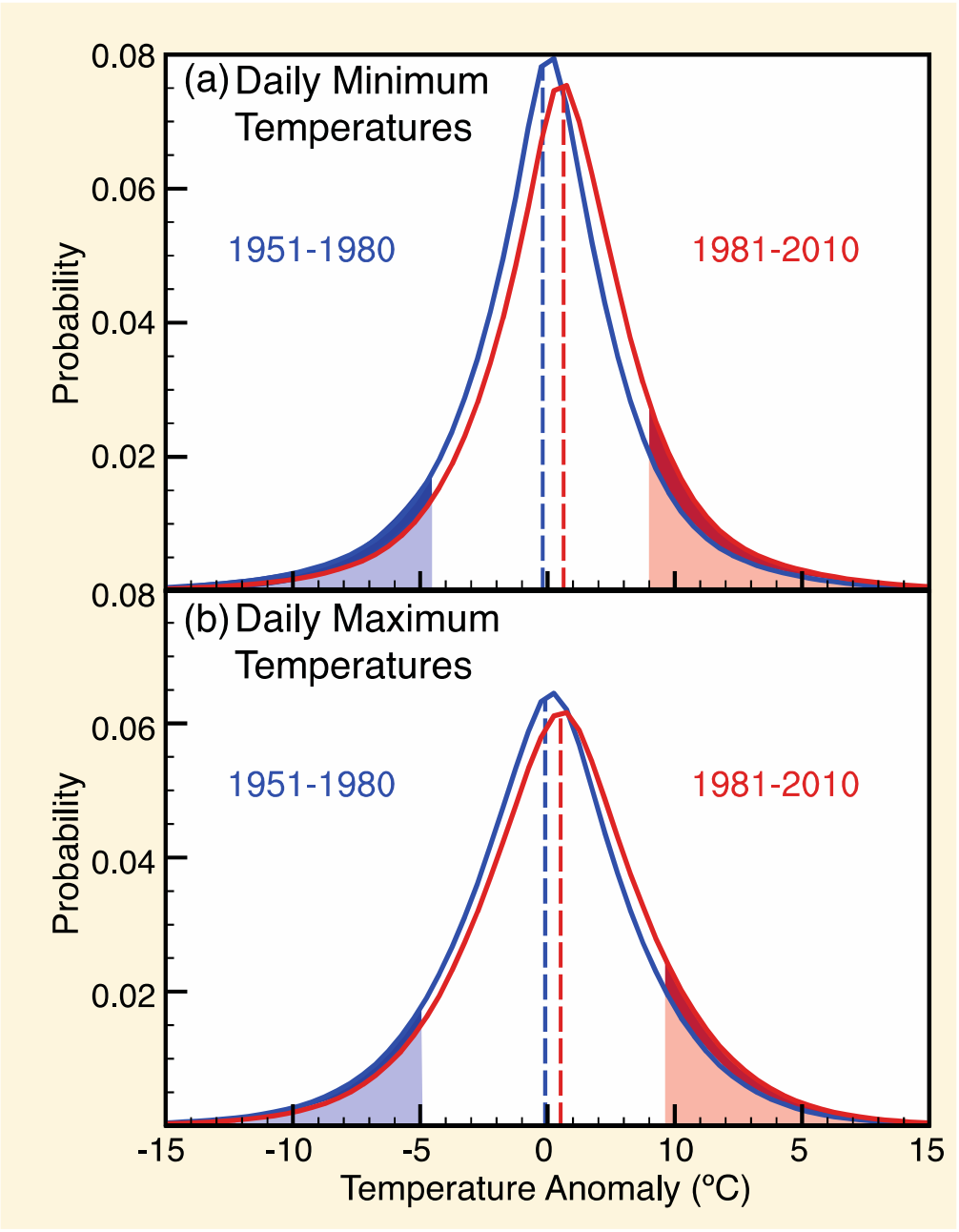
More rain falling in heaviest rain events (blue) in NE United States.

Changes in hurricane number less clear



Clear evidence
for changes
in temperature
extremes:

less cold events
more warm events



AR5 projections

global temperature rise likely (68% conf.) +1.5-5˚ C by 2100

sea level rise likely +0.3-1m by 2100

AR5 projections

global temperature rise likely (68% conf.) +1.5-5° C by 2100

sea level rise likely +0.3-1m by 2100

My opinion: probably closer to 1m

Two contributions to sea level rise:

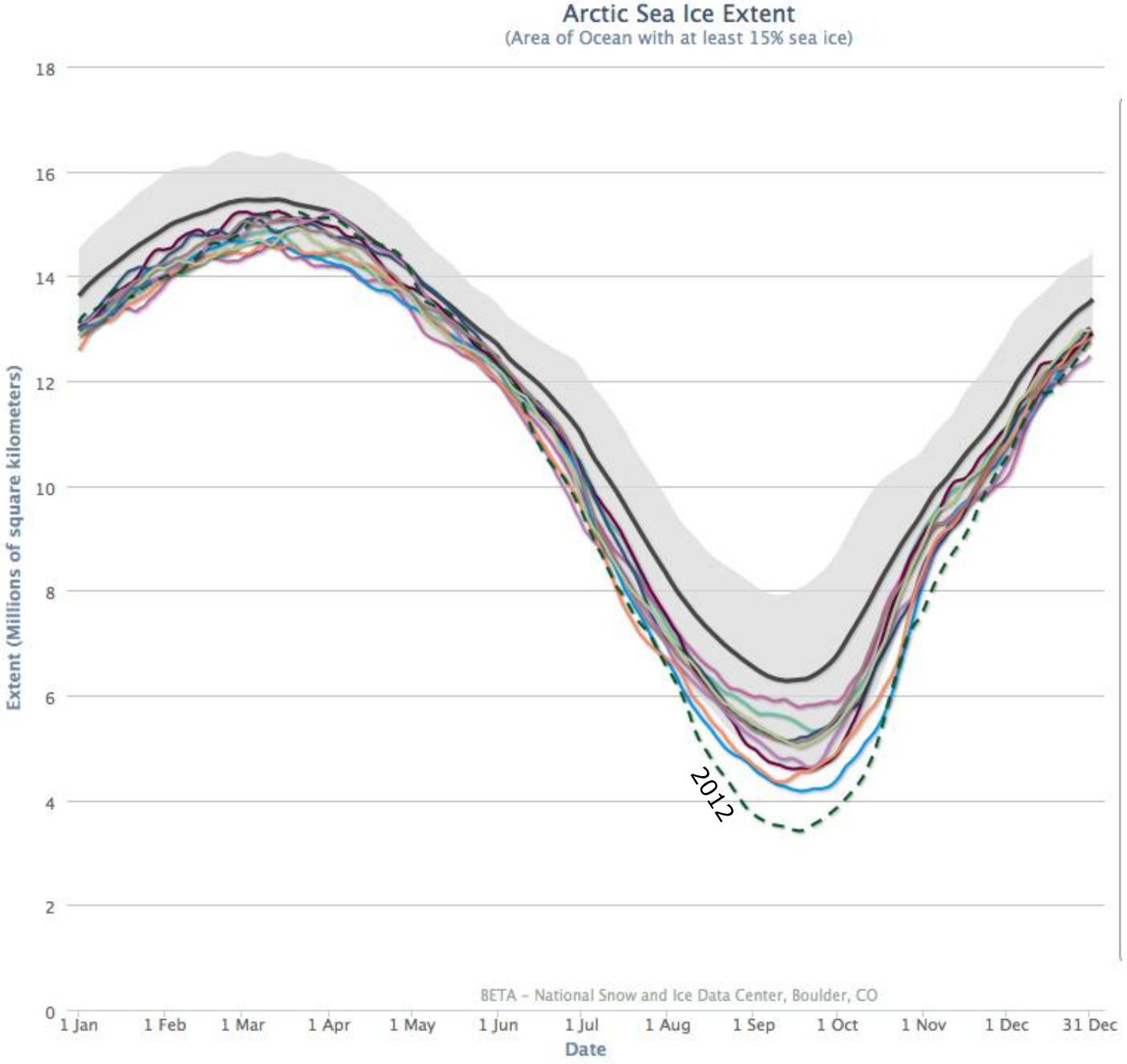
1) land ice melting

*How will the **cryosphere** respond to global warming?*

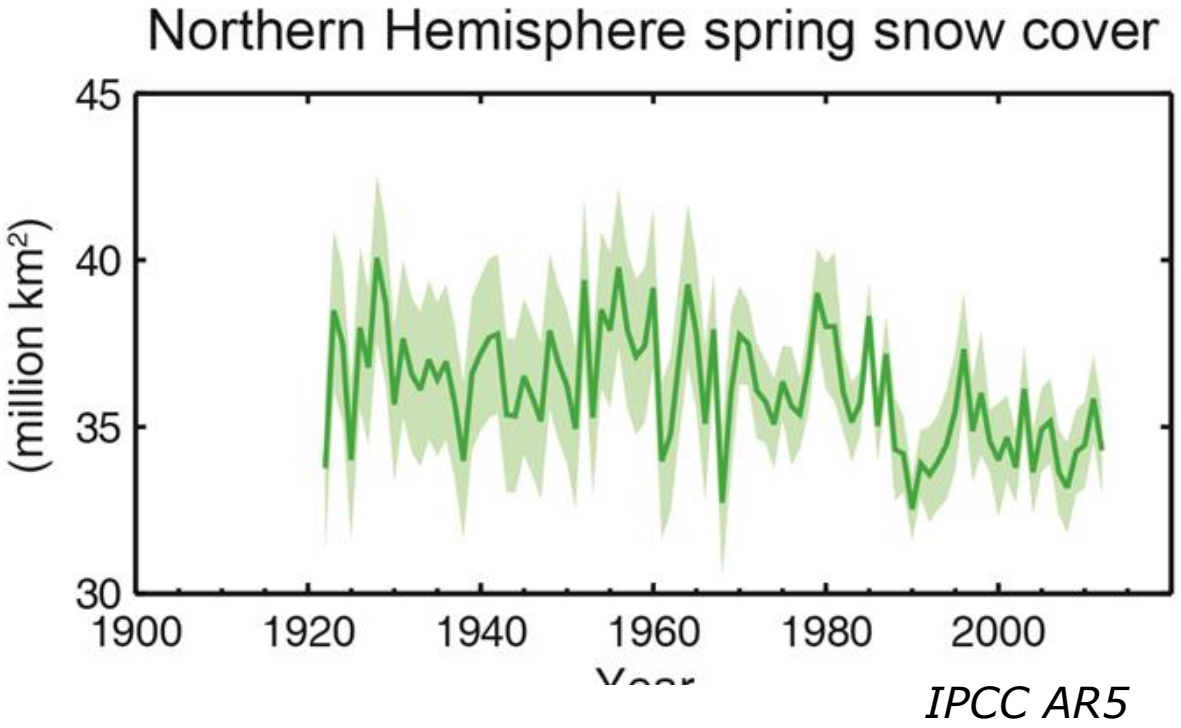
2) thermal expansion

Will scale with warming, but warming uncertain.

The **cryosphere** is responding fast to warming temperatures.



The uncertain sea level future



IPCC AR5

Sea level has increased
~10cm since 1960
~6cm since 1993

current rates are
+3.8mm/yr

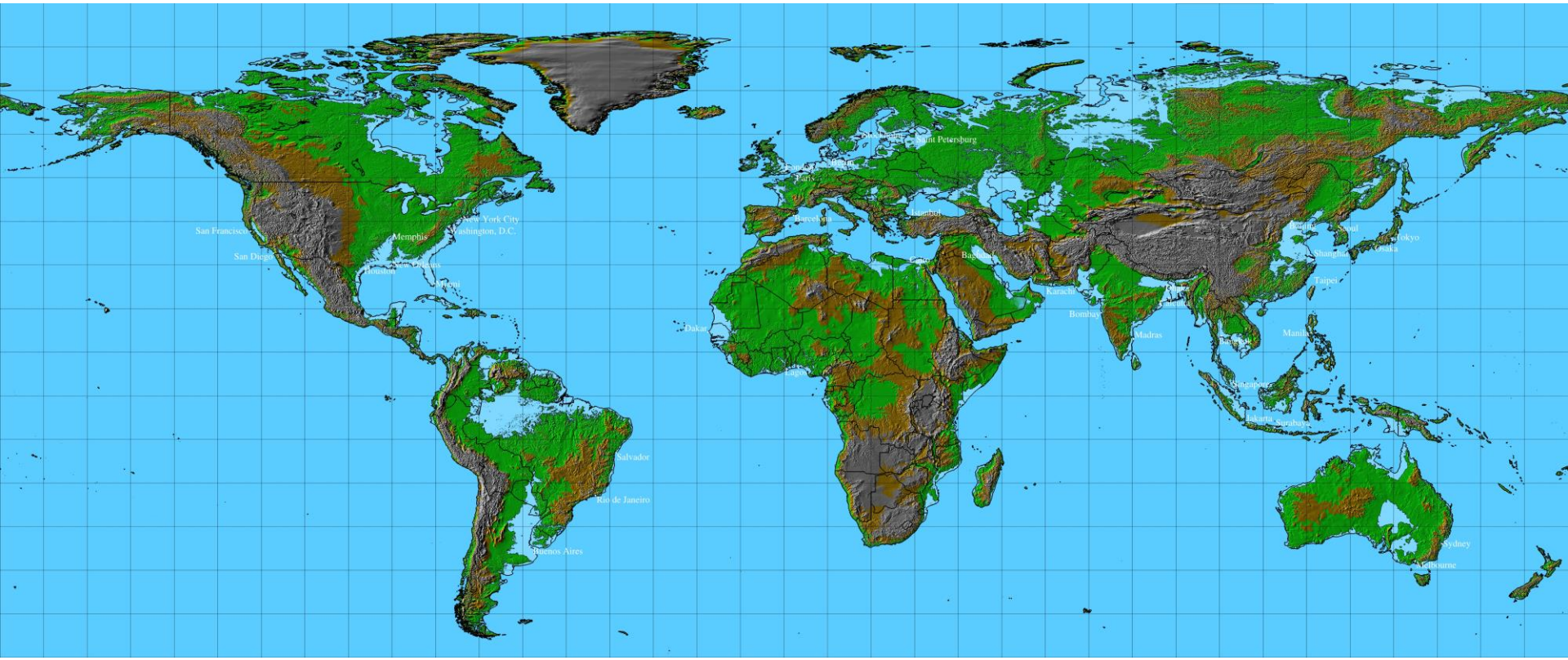
signs of accelerating
melting are now clear

mountain glaciers
particularly striking

Greenland is
already negative mass
balance; Antarctica
more complicated


From the Producer of *The Cove*
"ONE OF THE MOST BEAUTIFUL AND IMPORTANT FILMS EVER MADE"
– HUFFINGTON POST
"★★★★★"
– NEW YORK DAILY NEWS
CHASING ICE
A FILM BY JEFF ORLOWSKI
ACADEMY AWARD® NOMINEE BEST ORIGINAL SONG
EXCELLENCE IN CINEMATOGRAPHY AWARD SUNDANCE FILM FESTIVAL
SXSW AUDIENCE AWARD

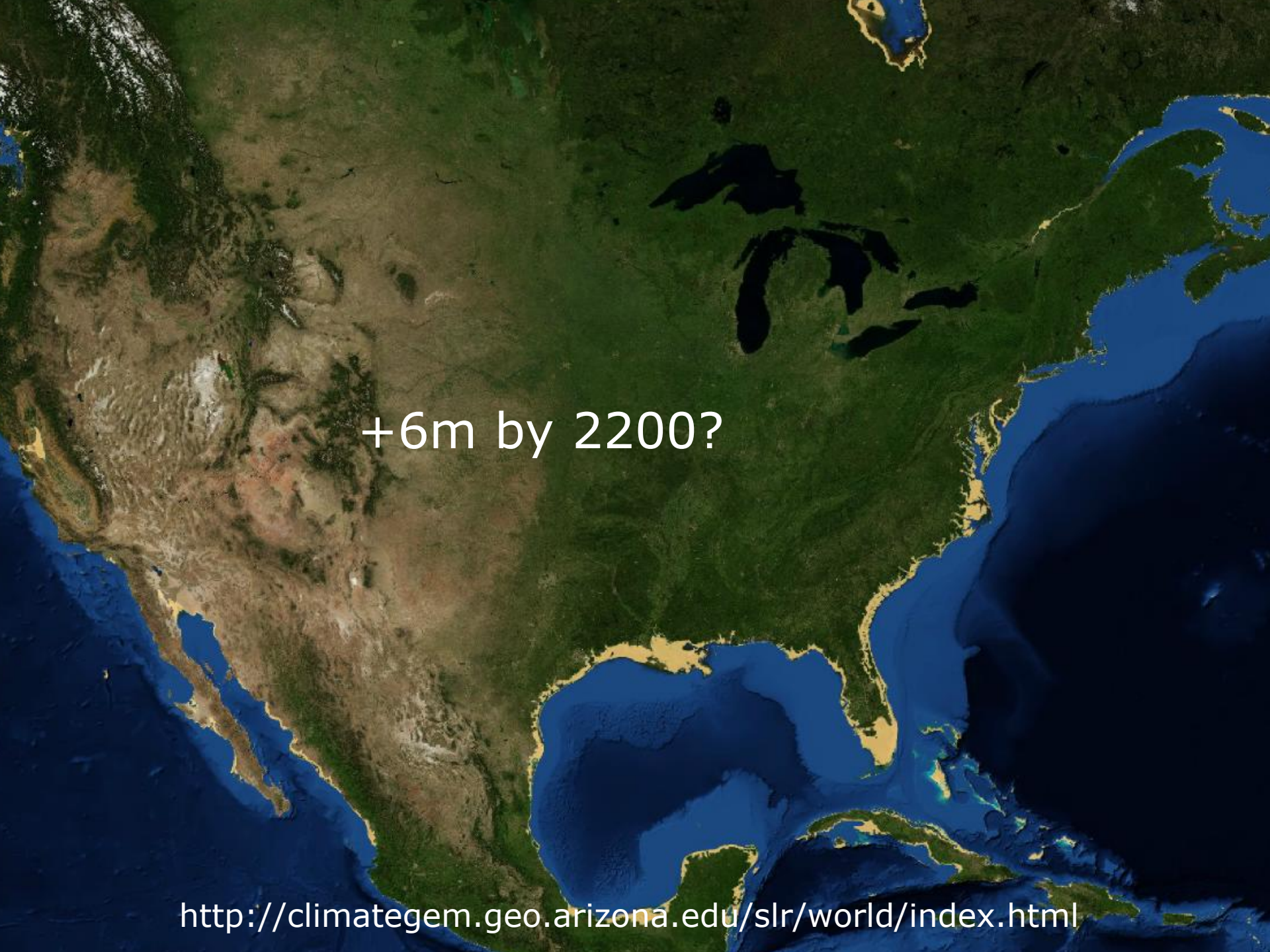
+100m sea level rise*



http://vrstudio.buffalo.edu/~depape/warming/World100-8190.jpg

Will this be our planet in 3000AD?

* Ice free Earth only good for +80m



http://climategem.geo.arizona.edu/slr/world/index.html

Measuring sea level changes in time:

1. Tide gauges

Located at coastal stations, they measure the relative change in sea level.

2. Satellite altimetry

Satellites in orbit around the planet use radar altimetry to measure the height of the sea level (accuracy of 2 cm).

Attribution of observed changes:

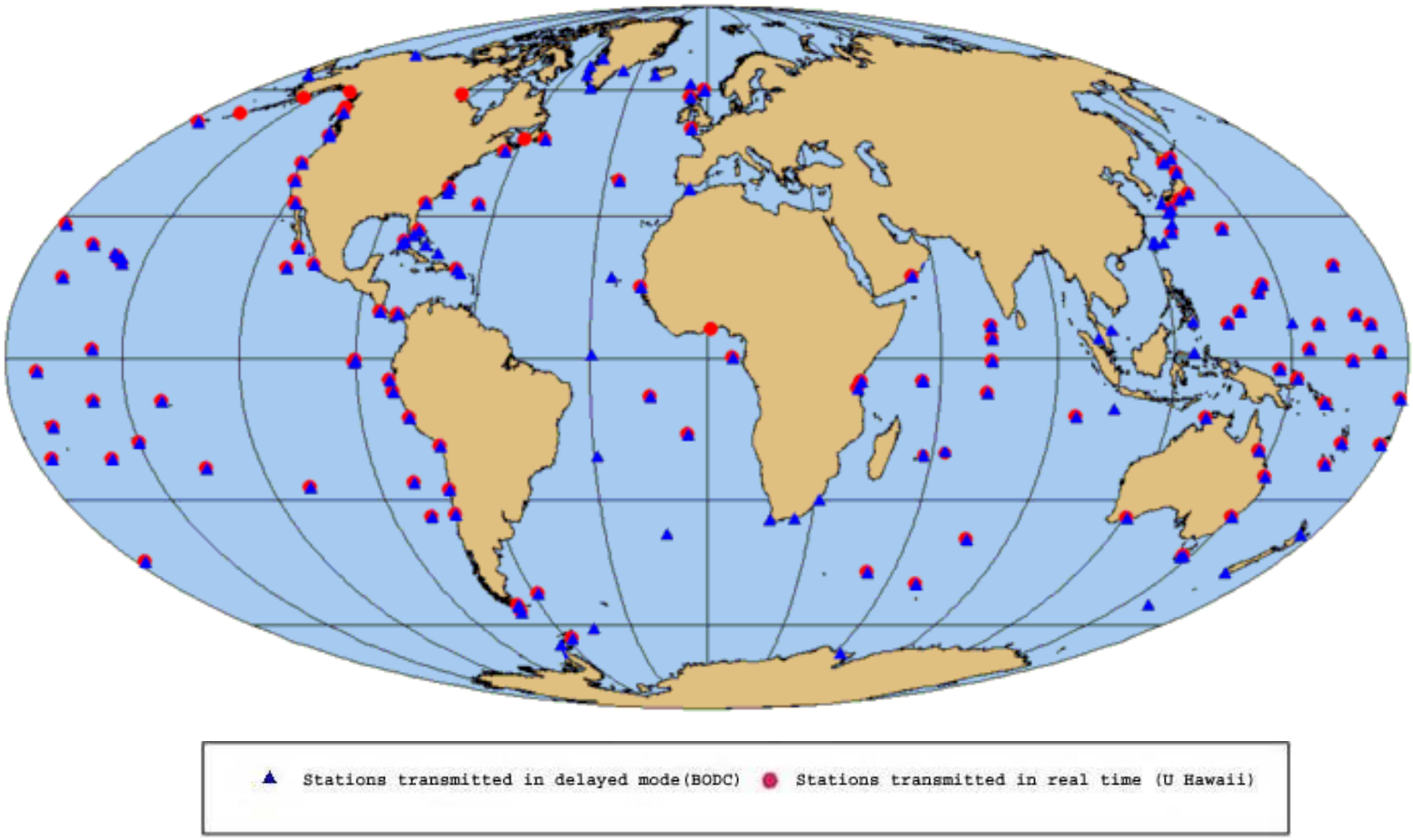
1. Ocean heating and thermal expansion (steric effect)

Requires detailed measurements of ocean heat content

2. Melting of land ice (eustatic effect)

Difficult to measure directly: indirect measurements include area extent of glaciers and snow-covered regions, and changes in global ocean salinity (ie last ice age)

WOCE Sea Level Stations as of February 2000 (from Tidal Gauges)



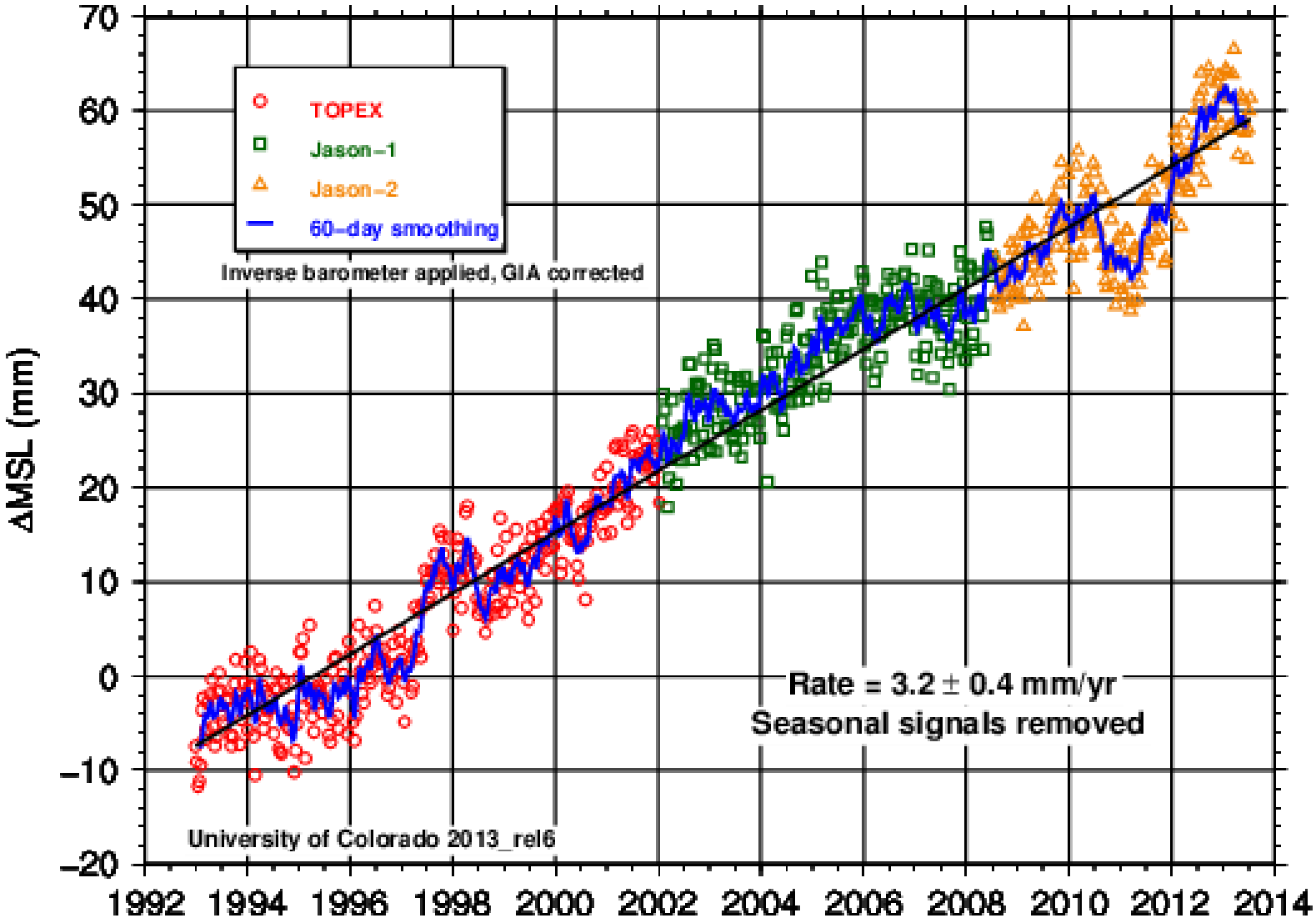
WOCE is the World Ocean Circulation Experiment → http://woce.nodc.noaa.gov/wdiu/

Sea Level trends based on Tidal Gauges

Sea Level Rise (mm/yr)	Error (mm/yr)	Data Used (years)	# of Tide Gauges	References
2.8	±0.8	1993-2009	~200	Church & White (2011)
1.7	±0.2	1900-2009	>38 since 1900	Church & White (2011)
1.9	±0.4	1961-2009	>190 since 1960	Church & White (2011)
1.43	±0.14	1881-1980	152	Barnett (1984)
2.27	±0.23	1930-1980	152	Barnett (1984)
1.2	±0.3	1880-1982	130	Gornitz and Lebedeff (1987)
2.4	±0.9	1920-1970	40	Peltier and Tushingham (1989)
1.75	±0.13	1900-1979	84	Trupin and Wahr (1990)
1.7	±0.5	N/A	N/A	Nakiboglu and Lambeck (1991)
1.8	±0.1	1880-1980	21	Douglas (1991)
1.62	±0.38	1807-1988	213	Unal and Ghil (1995)

http://sealevel.colorado.edu/content/tide-gauge-sea-level

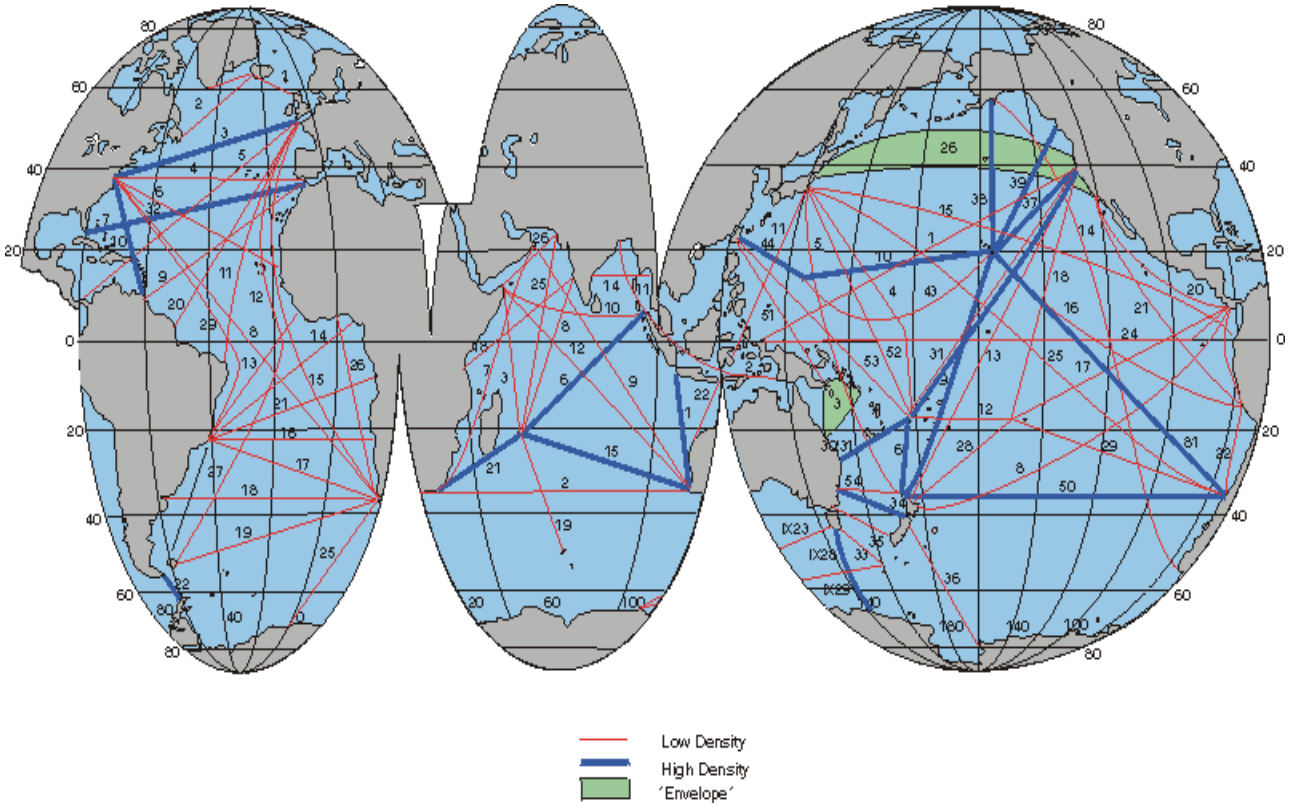
Satellite-derived sea level trends



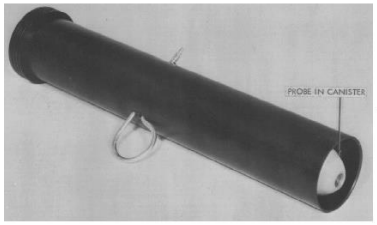
http://sealevel.colorado.edu

An example of Temperature measurements:

Expendable Bathythermograph (XBT) Lines



XBT



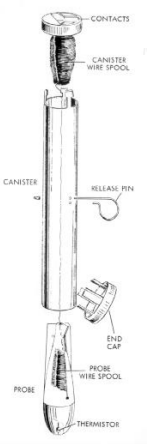
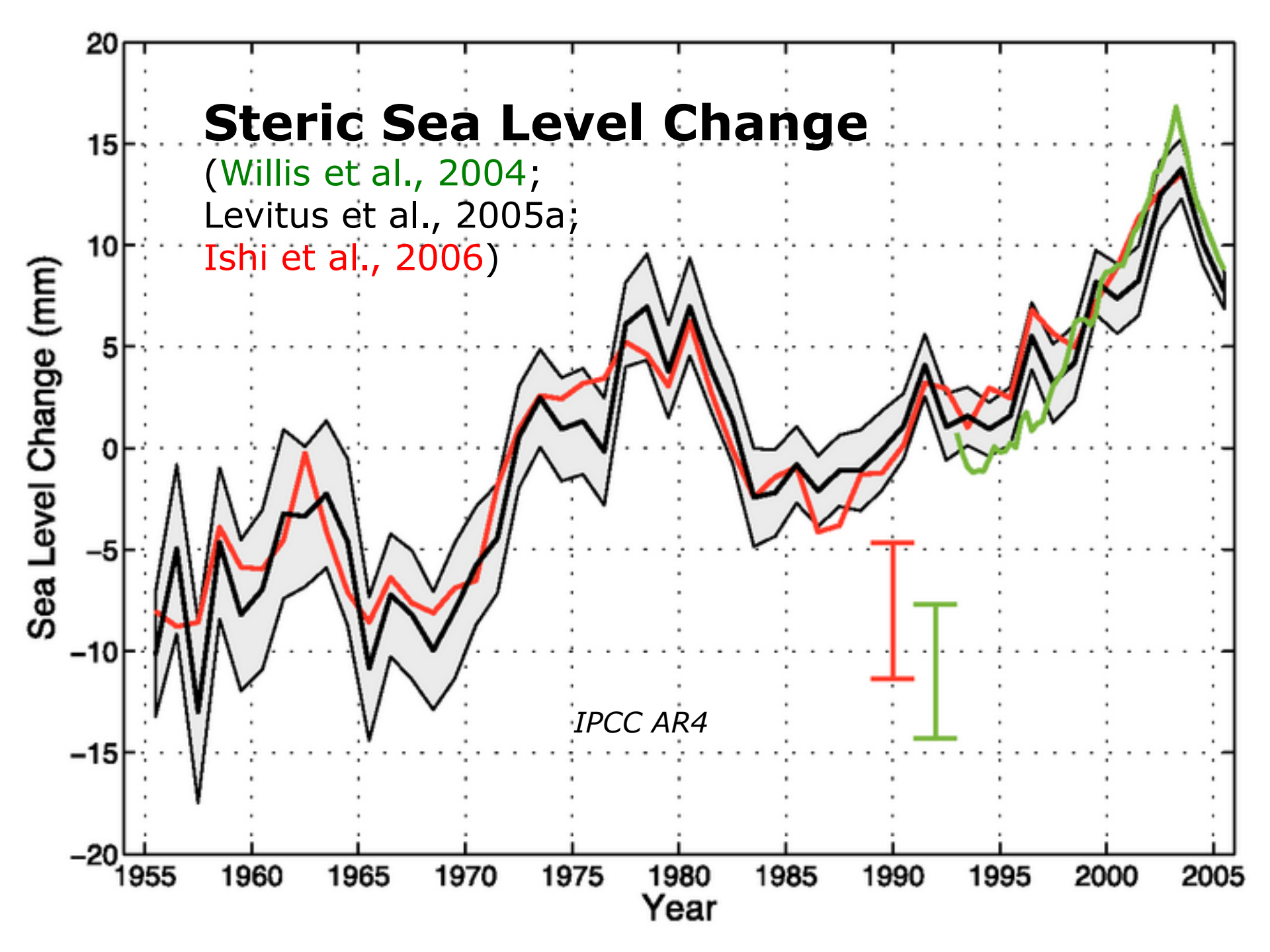


Fig. 1: XBT diagrams: Bathythermograph (probe) and exploded view.


Steric Sea Level Change
(Willis et al., 2004;
Levitus et al., 2005a;
Ishi et al., 2006)
IPCC AR4
Sea Level Change (mm)
Year
20
15
10
5
0
−5
−10
−15
−20
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005

TOTAL:

Sea Level Rise (mm/yr)	Error (mm/yr)	Data Used (years)	# of Tide Gauges	References
2.8	±0.8	1993-2009	~200	Church & White (2011)

THERMAL EXPANSION:

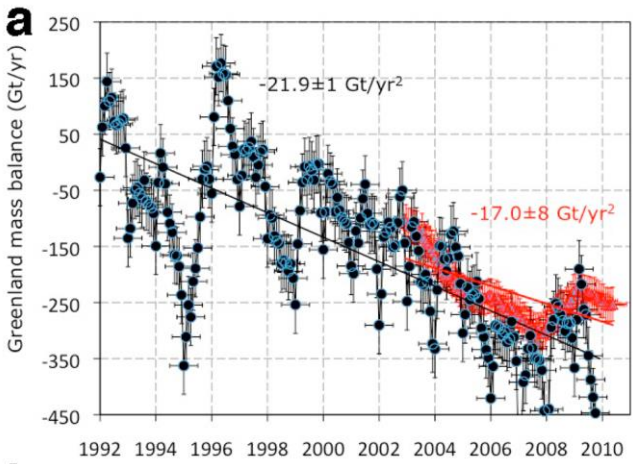
Reference	Steric sea level change with errors (mm yr^{-1})	Period	Depth range (m)	Data Source
Antonov et al. (2005)	1.2 ± 0.5	1993–2003	0–700	Levitus et al. (2005b)
Ishii et al. (2006)	1.2 ± 0.5	1993–2003	0–700	Ishii et al. (2006)
Willis et al. (2004)	1.6 ± 0.5	1993–2003	0–750	Willis et al. (2004)
Lombard et al. (2006)	1.8 ± 0.4	1993-2003	0-700	Guinehut et al. (2004)

So steric sea level rise is roughly 50% of recent sea level rise. Leaves 50% for land ice melting.

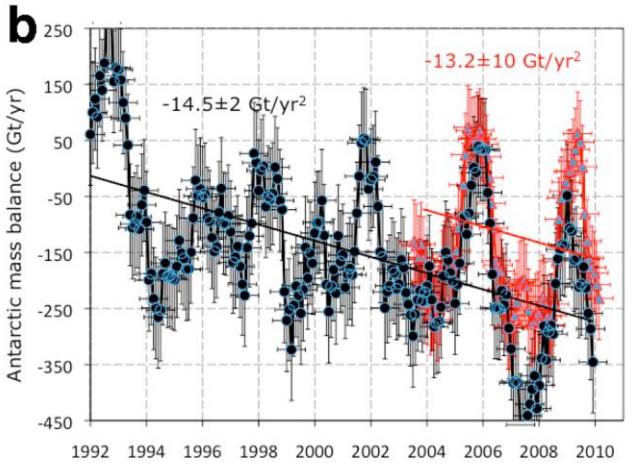
Can we detect melting of the polar ice sheets?

Mass balance estimates (blue/black = traditional; Red = satellite gravity) For

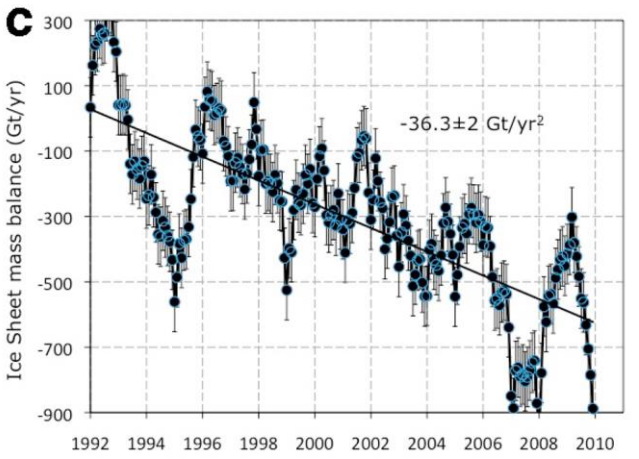
GREENLAND →



ANTARCTICA →

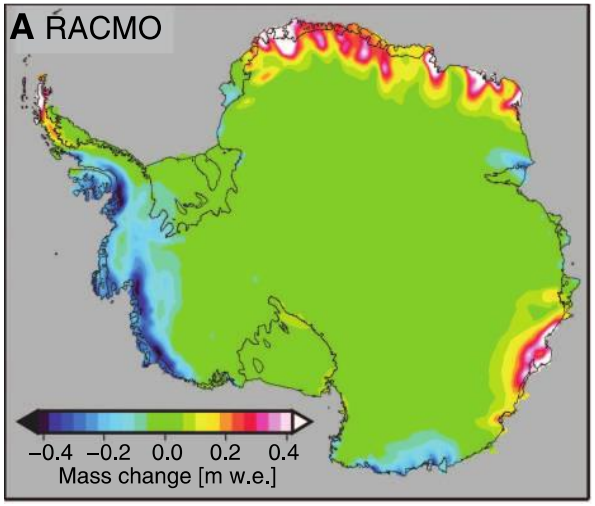


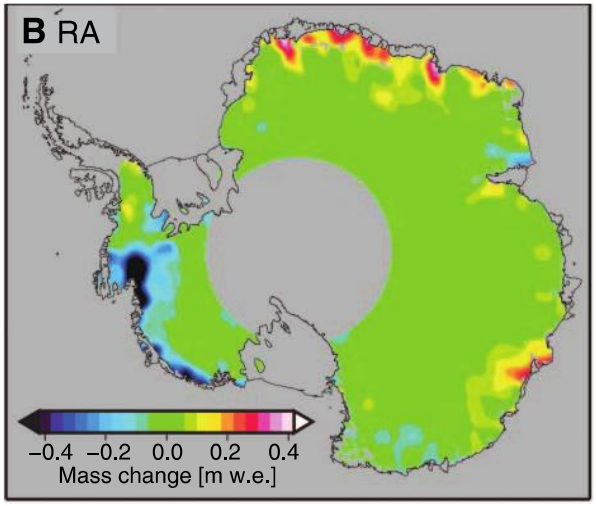
BOTH →

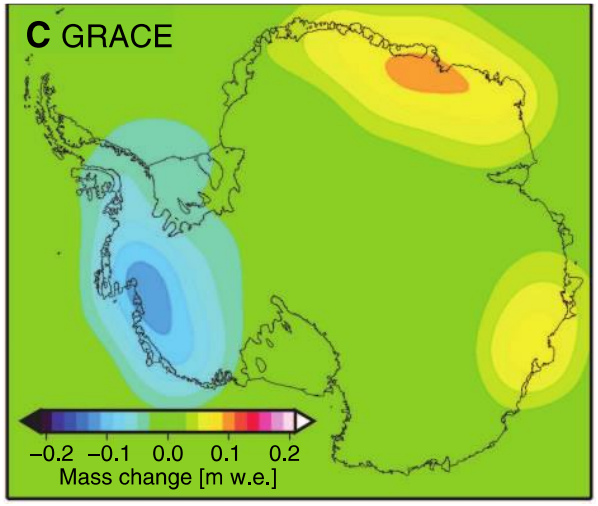


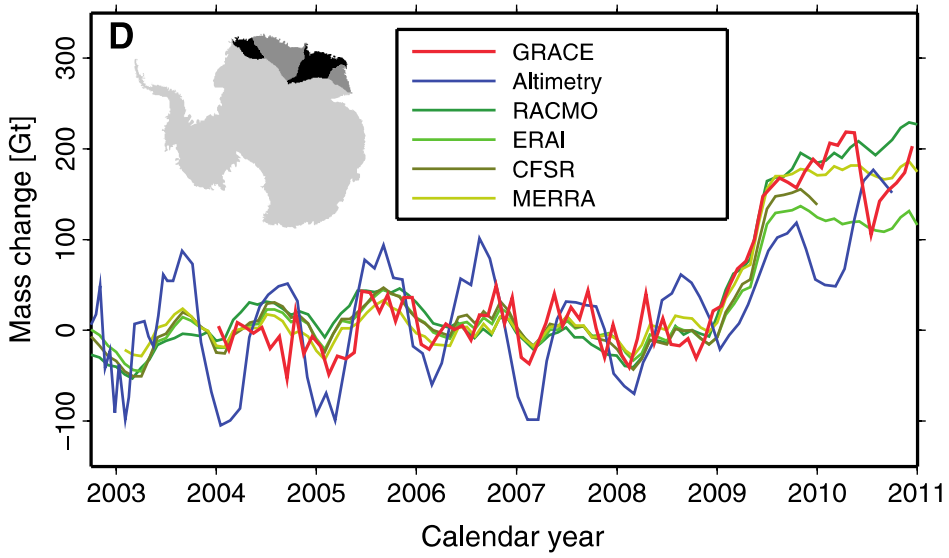
Rignot et al., GRL 2011

Mass balance of Antarctica is critical…



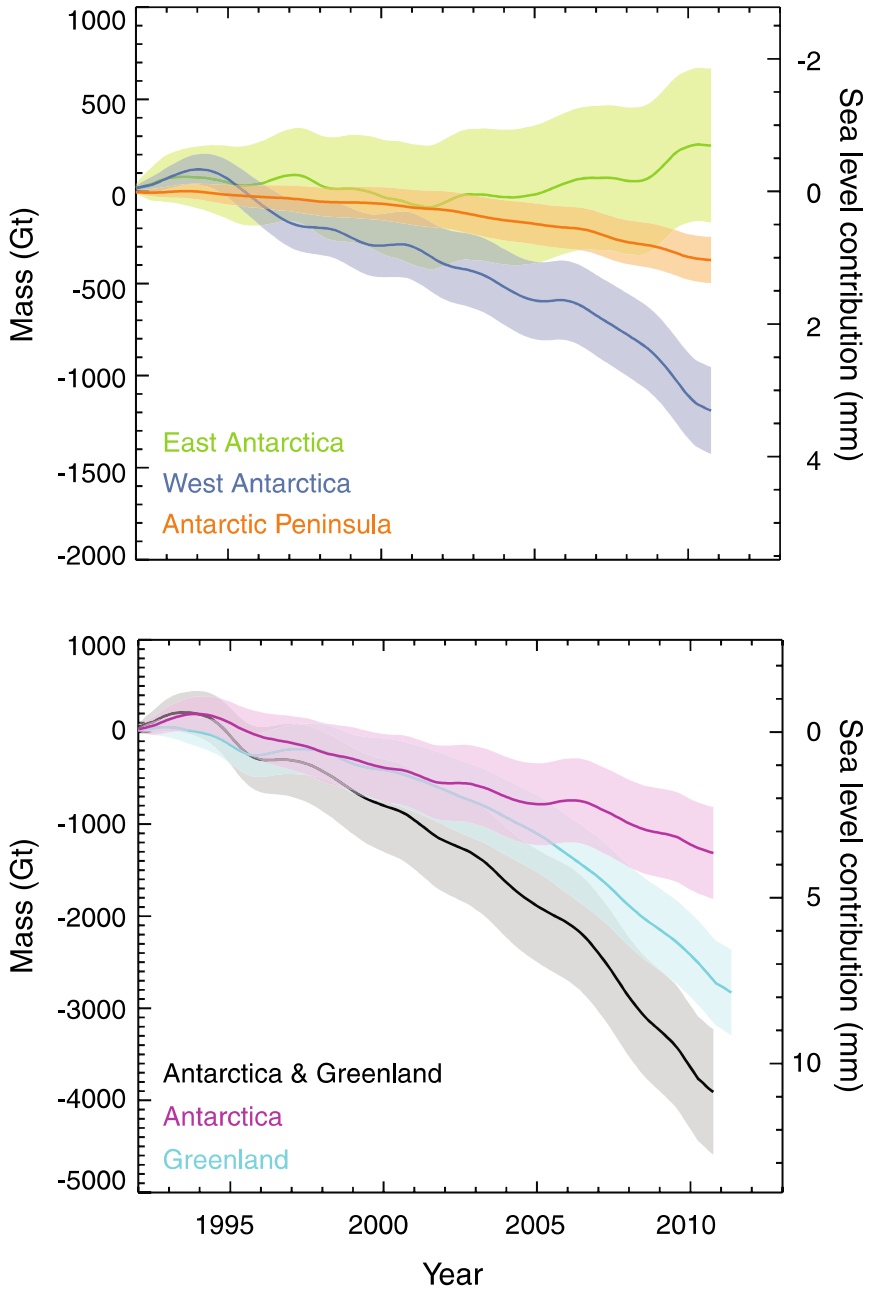






Some parts are growing

Shepherd et al., Science 2012



but cumulative mass balance is negative.

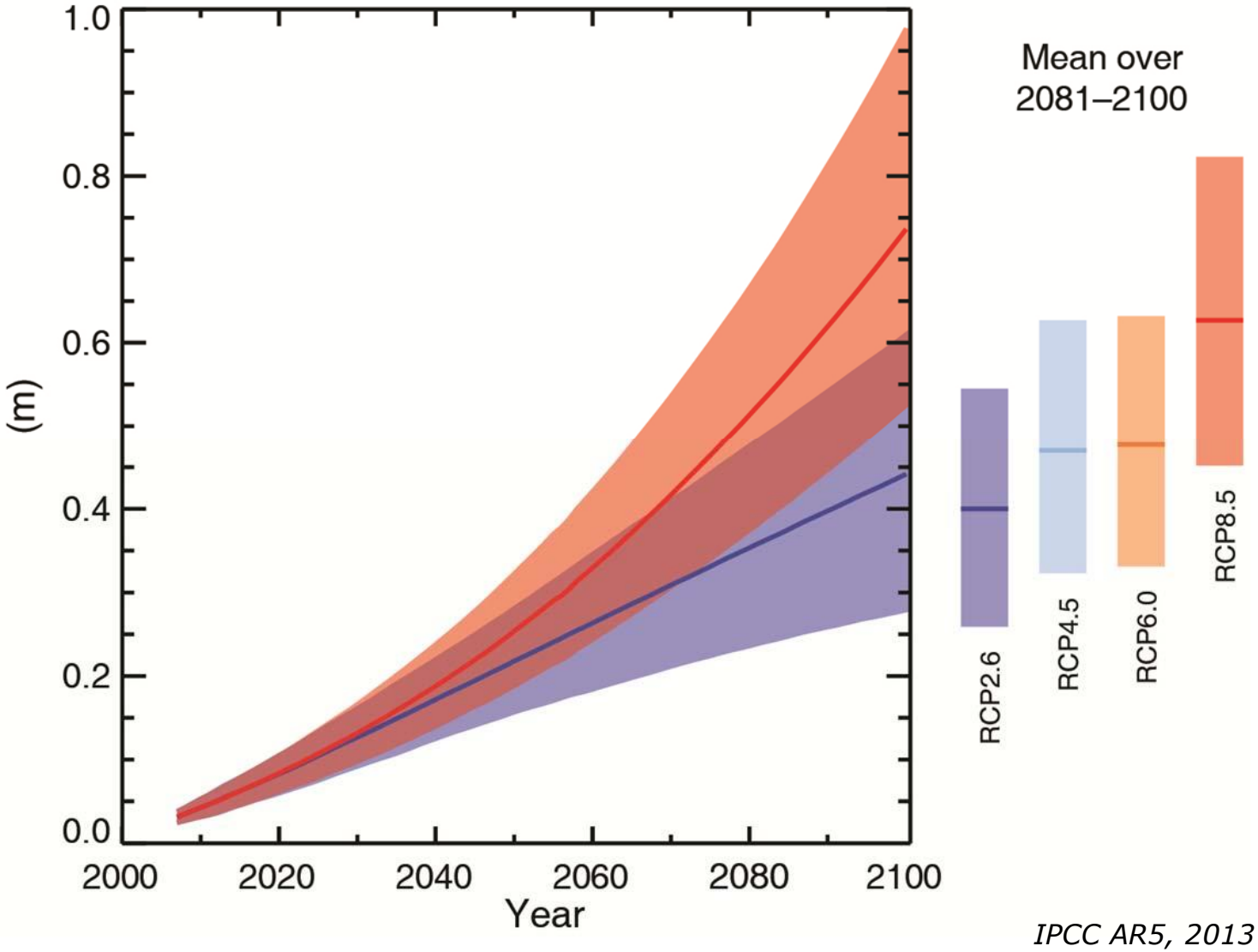
Translation: data support melting polar ice caps.

Implies that ice sheets have contributed 11±4mm of sea level rise since 1990.

[total observed = +60mm since 1993 from topex/jason]

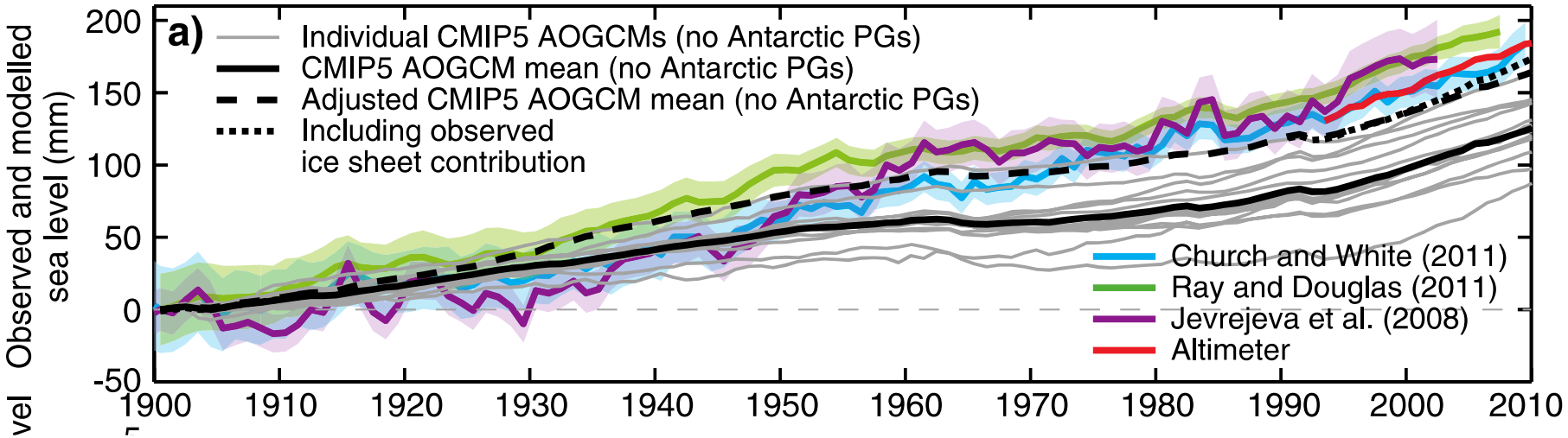
Shepherd et al., Science 2012

IPCC AR5 Global Sea Level Projection



IPCC AR5, 2013

But models have done a poor job of simulating historical sea level rise…



Some simple math:

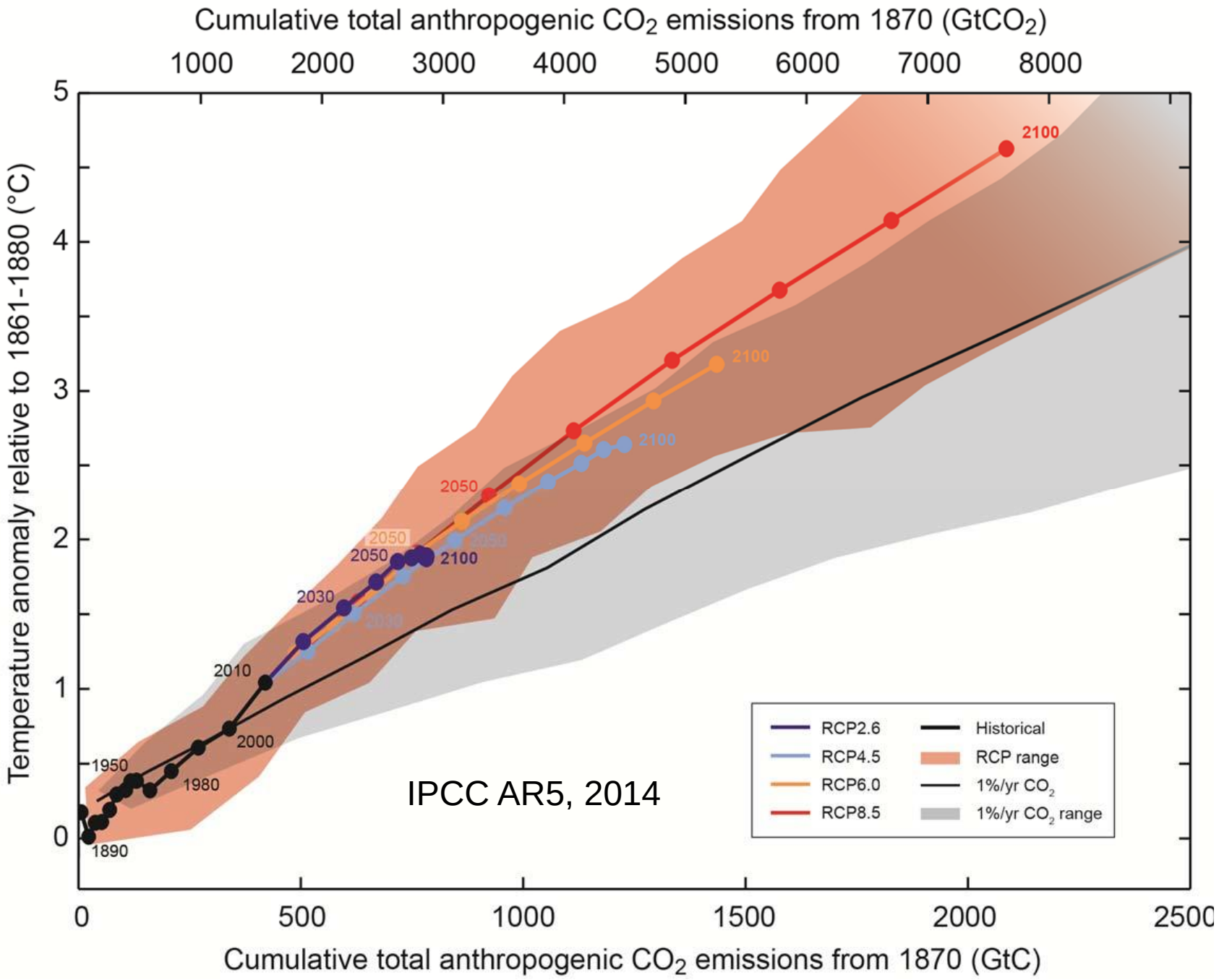
current sea level rise → +3 to 4 mm/yr

x 100yrs = +0.3m to +0.4m at 2100

but must account for acceleration…

Ex: if rate of rise doubles by 2050 to +7mm/yr,

then would be well over +1m by 2100


Cumulative total anthropogenic CO_2 emissions from 1870 ($GtCO_2$)
1000
2000
3000
4000
5000
6000
7000
8000
Temperature anomaly relative to 1861-1880 (°C)
0
1
2
3
4
5
0
500
1000
1500
2000
2500
Cumulative total anthropogenic CO_2 emissions from 1870 (GtC)
1890
1950
1980
2000
2010
2030
2050
2100
2050
2100
2050
2100
2100
IPCC AR5, 2014
RCP2.6
RCP4.5
RCP6.0
RCP8.5
Historical
RCP range
1%/yr CO_2
1%/yr CO_2 range